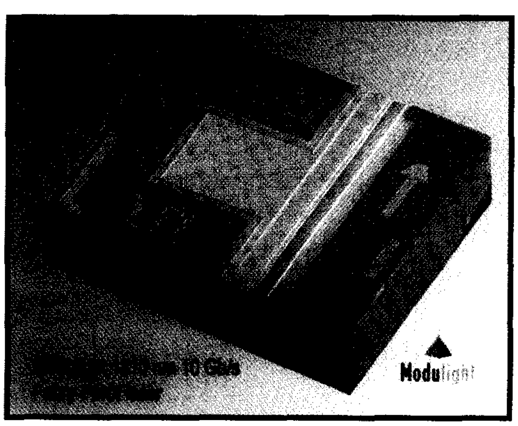
Roy Szweda

Diode lasers represent one of the twin pillars of the compounds industry. Commercially or technically, the field never lets up in terms of innovation. This article reviews progress in the field emphasising two of the most promising areas, those of VCSELs and of high power diode lasers. Each has to prove that it can compete in terms of performance and cost in well-established markets, as well as forging new ones.

Diode lasers continue to realise their potential

Photonics West having just passed, lasers have been high on the agenda. While there were fewer start-ups and record-breaking announcements, there is plenty of interest in lasers from a technical standpoint. Announced, in the last issue Osram Opto Semiconductors' prototype of an optical pumped semiconductor (OPS) disk laser with its high output power at 980nm is a promising light source for laser TV and many other applications.

One highlight of PW2003 was two companies sharing technologies to come up with a new approach to instrumentation. Aculight and Zia Laser's collaborative demonstration was of their 'broadly-tunable' quantum dot (QD) external cavity laser (ECL). They call it 'Dots-In-A-Well' technology, and it enables broad tunability through engineered quantum dot nanostructures grown within the active region of the laser. This provides tuning over a 100nm range with a good output. Combined, their technologies will provide much to interest the spectroscopy community. While this is an impressive technical achievement, eyes remain fixed on telecom applications of lasers. Not surprisingly, as this still represents the biggest market. With all the talk of 'dark fibre' the focus is on shorter distance datacoms. However, business is already experiencing intense pricing pressure. By way of example, Finland's Modulight completes its 1310nm Fabry-Pérot (FP) product family, having reached production status with the new FP chip for uncooled serial 10Gbit/s transceivers and transponders for very short reach link distances, [see photo.] The 100% tested FP chip can be bought as bare die for under $50 in quantity.



Petteri Uusimaa, Modulight's President and CEO: "Customers are not willing to invest extra in a DFB laser that allows 10 km transmission if it's used for a 2 km link. This might have been the case in 2000, but that's not the way this industry is operating in 2003. Our FP laser gives access to the required performance with reduced source cost."

Lasers in the lab

Great promise is the term that has always been associated with the laser diode family. Despite being around for several decades the business is far from exhausted. In fact recent years have seen steady gap filling in the emission spectrum. From the longest wavelength of the IR through to UV, laser diodes have been lab demonstrated if not actually all yet reaching commercial product stage.

This is not the end of the story, however, as power output has also been increasing. So much so that laser diodes now also serve as compact energy sources. For the future the market will pursue parallel courses, signal processing (fibre optics and data storage, for example) alongside high power devices (HPDLs).

Coherent emission at the shortest wavelengths has long been an intriguing challenge for researchers. Just recently there have been better indications that violet lasers are approaching larger scale commercialisation. Collaborations and settlements between Japanese companies for the Blue-Ray next-generation DVD technology have made the headlines, but products are not expected for some time yet.

Of course, the poor performance of the telecom sector tends to overshadow all else in the diode laser business. But closer inspection reveals progress across a diverse range of laser diode types. This is of interest not only for the shrinking number of device and system makers, but also their suppliers, ie materials and equipment companies. Semiconducting precursors, wafers, epitaxy and characterisation equipment are all having to pull together to provide the necessary devices. And as reported recently, the laser business is moving more towards automation for packaging and modules.

That said, technically diode lasers have many promising categories for review. An ongoing research topic has been the growth of emitters on silicon. This has become especially interesting to research groups around the world following Motorola's revelatory hetero-epitaxy technology using dielectric buffer layers.

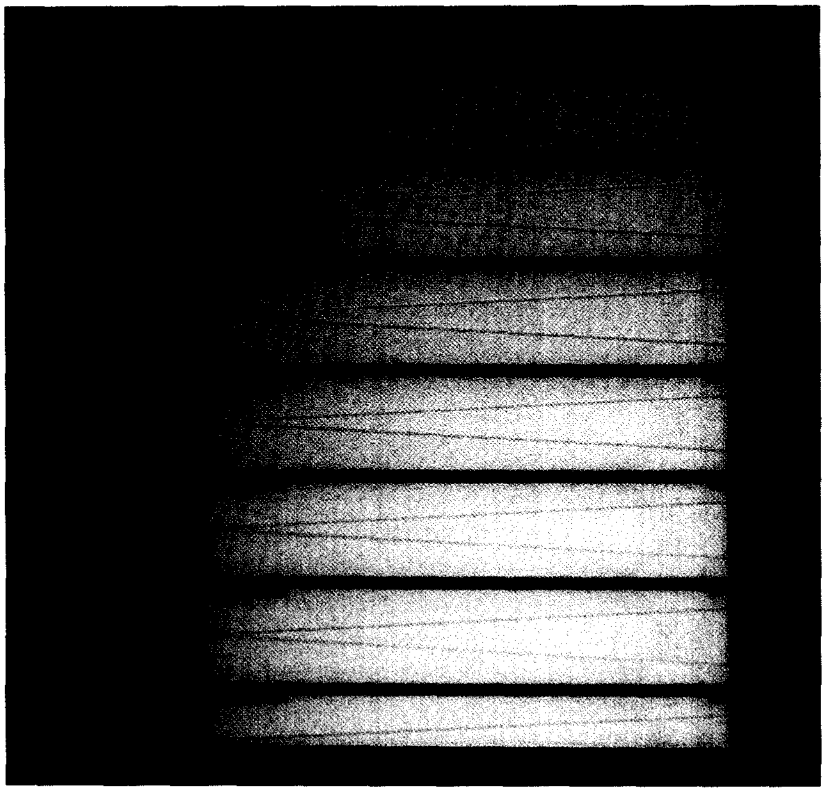
For example, GaAs diode lasers have been grown on silicon using low-temperature bonding of MBE-grown GaAs wafers with silicon wafers by workers from the Microelectronics Research Group, FORTH, IESL and University Crete, plus NCSR 'Demokritos', Institute of Microelectronics, together with the Max Planck Institute of Microstructure Physics in Germany.

They have used an intermediate spin-on-glass (SOG) layer. TEM revealed that quality of the bonding was good with no micro-cracks or dislocations. Other measurements on GaAs/AlGaAs MQW were equally encouraging, the only problem experienced was with a tensile stress due to the different thermal expansion coefficients of GaAs and Si. Nevertheless, they were able to fabricate diode lasers with etched mirrors on silicon. These showed performances similar to reference devices fabricated on GaAs substrates, they said.

VCSELs

Not so long ago, everyone had great hopes for VCSELs. They should have been more cautious in their market estimates. The market was going to be dominated by telecom and the number of suppliers grew too fast, increasing competitive pressures and hastening the onset of market troubles.

It was thought that perhaps other applications might take up VCSELs but this has so far proved equally ephemeral. The potential in these devices remains huge. Much technical refinement continues in expectation of realisation. Interestingly, researchers and manufacturers are looking to exploit either MOVPE or MBE but are having to use new techniques to meet the challenging task of fabricating VCSEL structures. For example, in Berlin, in-situ monitoring is being used to refine MOVPE for 650nm VCSELs. The Ferdinand-Braun-Institut für Höchstfrequenztechnik and Technische Universität, Berlin works with instrument company LayTec GmbH to perfect the process.



HPDL section from the Fraunhofer Institute for Applied Solid State Physics (IAF) with tapered resonator each emitting two watts at an M^2 of less than 3. The laser structure is made with an InGaAs/AlGaAs/GaAs quantum well and emits at a wavelength of 940nm.

Also in Europe, a Polish-Swedish collaboration has reported investigations of the optical properties of active regions in MBE-grown VCSELs. The Department of Physics and Technology of Low Dimensional Structures, Institute of Electron Technology in Warsaw has been working with the Department of Physics and Measurement Technology, Linköping University. In order to further understanding of the optical processes within the active regions of VCSELs, several experimental methods have been applied. MBE grown Bragg reflectors and microcavities were investigated by a combination of optical techniques characterised so as to optimise the whole laser structure.

The optoelectronics industry is not only interested in discrete devices. Hybrid and monolithic integration are posing huge challenges to engineers and designers as they seek to fully exploit the potential of devices such as VCSELs. Another advantage of this family is the ability to be monolithically integrated into arrays. This opens up numerous possibilities in telecoms and in sensing, etc. Researchers have also been combining

VCSELs with MEMS, so-called micro-opto-electro-mechanical system (MOEMS).

At the Ecole Centrale de Lyon, MOEMS are being developed involving the manipulation of optical interferences. For this the basic building block is a multi-air-gap/suspended-membrane structure. The structure is formed by micro-machining of multi-layered III-V heterostructures.The workers say that the building block is very generic - it can be designed in a variety of ways allowing for production of a wide range of optical functions. They are looking to exploit devices such as tunable filters for WDM systems, tunable photodetectors, and tunable VCSELs.

In-situ monitoring can have other connotations as regards VCSELs.A group at the University of Heidelberg has reported on the in-situ detection of potassium atoms in high-temperature coal-combustion systems using near-IR diode lasers.

Direct tunable diode laser absorption spectroscopy at 769.9 and 767.5 nm has been used to measure potassium atom concentrations in situ in the flue gas of coal dust combustion systems.

Even though FP and VCSEL lasers were used for the spectrometry, the group states that the wide continuous current-induced tuning range of the VCSEL of 20 cm^{-1} (compared to 1 cm^{-1} for the FP) make the VCSEL ideal for species monitoring in high pressure processes.

Of course, there is considerable interest in VCSELs in Taiwan because the market will be high volume and built on epitaxy processes, both of which are key parts of Taiwanese strategy in III-V devices. One of the keys to successful manufacture of these often troublesome devices has been contact formation. A project in Taiwan has studied the effect of indium tin oxide (ITO) - a well-understood material frequently used in LCD manufacture - as an ohmic contact for their 850 nm GaAs oxide-confined VCSELs. Scientists at the National Tsing Hua University, together with the National Cheng Kung University and ITRI's Opto-electronics & Systems Laboratories have used ITO as a p-type ohmic and achieved results as good as those from the conventional VCSELs route with Au/Zn/Au or Ti/Pt/Au ohmics.And their ITO VCSELs showed light output power 1.27 times better than those of conventional VCSELs.

Building on this they have developed a new process method to improve the light output power of VCSELs by filling the ring trench with Al metallisation.They say that this exhibits a higher quantum efficiency and light output power of 1.45 times higher than those without the filling.The trench filler has the added benefit to acts as a mirror to reduce output power loss.

HPDLs

III Vs Review monitored progress in high power diode lasers (HPDLs), last year, revisiting the impressive efforts in Germany's national HPDL programmes. One of these, NOVALAS, coordinated by the Fraunhofer Insistute for Applied Solid-State Physics IAF ended in December last year. Another MDS coordinated by Rofin Sinar is still running.This consortium from 16 industrial partners and 6 IC research institutes includes all prominent German laser experts.

An example of the latest results from the collaborative research is shown. HPDL development in the wavelength regime of 880nm to 1080nm was focused on enhancing the output power of a single laser bar and improving the brightness of each single emitter. .A chief goal was to secure the future laser market for Germany on a long-term basis.This is strategically very sound given the country's importance as regards laser finishing techniques world-wide. Germany holds a major share of the global industrial laser market, as much as 40%. It is vitally important to secure future markets via the new generation of HPDLs.

A wide range of HPDL products is now available. Costs of current HPDL systems are very competitive with the mainstay of the IR market, the CO_2 laser. But in order to achieve competitive output powers they have to be combined in a bar or stack.As a result virtually all exhibit beam quality which is inferior in one or more respects to the traditional CO_2 and Nd:YAG lasers.This is due for the most part to incoherent coupling of many lasers in a bar or stack. Progress so far indicates that improvements will soon appear enabling even higher power products to challenge the existing market as well as forge new ones.The poor beam quality at higher powers means that HPDLs are not the optimum choice for cutting and deep welding.The strength of the HPDL are in applications such as surface hardening, plastic or sheet welding, soldering and above all pumping which can enjoy the attractive running costs for HPDLs, well below those of conventional lasers. HPDLs have typical wall plug efficiency ratings of 30% or better. They also have very low cost of ownership compared to older types. NOVALAS and related projects have shown some very convincing demonstrations to confirm the potential of this approach.

Compactness is a HPDL virtue lending itself to certain existing and new applications. Examples include removal of industrial epoxy grout as demonstrated by the Department of Mechanical, Aerospace and Manufacturing Engineering, Laser Processing Research Centre, at UMIST.

UMIST engineers have also worked with the Nanyang Technological University (NTU) in Singapore on the surface treatment of refractories. Comparing CO_2 and HPDL treatments, wear rate and wear life characteristics of an alumina-based refractory were greatly enhanced.They noticed that the wear life of the HPDL treated surface exceeded that of the CO_2 laser treated surface in all the test environments owing to its finer, more densely packed and less cracked microstructure.

Certain types of HPDL are also interesting for pumping up-conversion fibre lasers or as sources for Raman amplifiers in telecom systems. The research group at the Ferdinand-Braun-Institüt für Höchstfrequenztechnik, in Berlin, has studied indium incorporation behaviour into pseudomorphic InGaAs-quantum wells with extremely high indium content grown by LT-MOVPE. Structures with a slightly reduced In-content, emitting at 1120nm, were processed to broad-area devices (100 x 1000 microns) and show output powers up to 12W, which corresponds to a record high internal power density of $23MW/cm^2$, with a good reliability. Lifetime tests show the potential for high-power applications.

Finally, several groups are investigating reliability issues in HPDL bar packages. One has been conducted by the Department of Mechanical Engineering, High Density Electronics Center (HiDEC) at the University of Arkansas, USA.

They have focussed on the die-attachment interface, which must be defect free and stress managed for reliable optical alignment. Microscopic defect analyses of the die attachment interface and device stress were carried out. These showed that intermetallic compounds and microscopic physical defects at the die attach interface are detrimental to transient heat transfer, and thus, overall package reliability. Using micro-Raman spectroscopy, it was found that tensile stress near the bar-package interface increases with aging for the first few hundred hours and then decreases with further aging.

SiGe QCLs

To close this overview there could be no better choice than a quick look at progress in quantum-cascade lasers (QCLs). In principle, QCLs offer performance superior to other diode lasers at the same wavelength by factors greater than 1000 in terms of power, claimed its originators at Bell Labs.They can be made to emit at any wavelength over a very wide range using the same combination of materials in the active region. Practical applications beckon, due to the present gap in coverage for certain materials such as pollutants. These have absorption 'fingerprints' in the IR outside the capability of traditional diode lasers.

QCLs have long been seen as a good opportunity for III-Vs. Literature is replete with papers showing record-breaking performance, so it was expected that QCLs would sit alongside DFBs, FPs, VCSELs, etc, in the III-V component catalogues. Recent work indicates that as in certain microelectronic devices such as low noise receivers, a threat is looming.

No overview can be complete without a look at what is happening in SiGe. Both Si and Ge are indirect band gap materials. Interband emission is very inefficient. But a laser has been brought a little closer, if recent work is any indication.

A new paper 'Si/SiGe quantum-cascade emitters for terahertz applications' describes a collaboration between the University of Sheffield, University of Cambridge, University of Leeds, Heriot-Watt University and TeraView Ltd, the new Cambridge based start-up. Si/SiGe QCLs have much to offer, not the least being for terahertz applications, a very promising area for instrumentation and medical imaging.

Today, the terahertz frequencies are under-utilised owing to the lack of practical sources and detectors. Potential applications include medical imaging, bio-weapon detection, security monitoring, gas sensing, pollution monitoring and molecular spectroscopy. While there are terahertz sources available, few match the characteristics desired by the market.They should be compact, efficient, low-cost high-power sources such as a laser. Further, if silicon-based, it would allow monolithic integration with standard Si-based microelectronics.

The DARPA-sponsored project has investigated "the physics of LH1 to HH1 intersub and transitions in the Si/SiGe system as a first step in demonstrating high efficiency quantum-cascade staircase emitters" with the aim of producing a laser.

The SiGe epiwafers used were purchased from QinetiQ. Unfortunately for compound semiconductors, the results have been encouraging.These suggest that appropriately designed and optimised Si/SiGe heterostructures should allow the realisation of a terahertz quantum cascade laser.